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ORIGINAL RESEARCH

Residual Effect of Biochar and Legumes on Soil Fertility, Yield and Yield Components of Wheat

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ABSTRACT: Biochar and the use of legumes in cropping systems are considered sustainable approaches to boost crop yield and preserve soil fertility. In the current study, the effects of leftover biochar and previously planted legumes on wheat yield and soil N status were examined at various nitrogen (N) levels. The experiment included testing two levels of previously applied biochar (0 and 50 tons ha^{-1}), three legumes under four levels of N (0, 60, 90, and 120 kg ha^{-1}), cowpea (*Vigna unguiculata*) for fodder, Sesbenia (*Sesbenia grandaflora*) for green manuring, and mung bean (*Vigna radiata*) for grain. Results showed that biochar application enhanced wheat tiller m^{-2}, spikes m^{-2}, grains per spike, thousand grain weight, grain yield, biological yield, and soil total N status by 3%, 6.5%, 3.7%, 1.8%, 7.8%, 9.5%, and 11%, respectively. Moreover, applying nitrogen at a rate of 90 kg ha^{-1} increased the amount of wheat spike m^{-2} by 20%, grain spike^{-1} by 10%, grain yield by 70%, biological yield by 48%, harvest index by 27%, and the N content of the grain, straw, and soil by 13%, 14%, and 36% respectively. Meanwhile, 1000 grain weight resulted higher by 6.17%. Legumes that had been previously seeded outperformed fallow and increased spikes m^{-2}, grain yield, biological yield, grain N content, and soil total N content by 8.2%, 11%, 6.78%, 25%, and 42%, respectively. It is determined that applying biochar to the summer gap left by legumes can increase soil fertility and wheat output.

KEYWORDS: Biochar, legumes, nitrogen, wheat yield, soil fertility.

1. Introduction

The various challenges faced by agricultural development such, as the reduction in land, climate change, scarcity of water unpredictable temperature changes, shifts in rainfall patterns increasing input costs and significant migration of people from rural to urban areas highlight the urgent need to improve agricultural productivity through innovative crop production strategies. Wheat (*Triticum aestivum* L.) a crop that plays a major role in meeting a large portion of global human dietary energy requirements has experienced a rise in demand recently due to its product's availability at more affordable prices compared to other cereal crops. According to the Food and Agriculture Organization (FAO) it is projected that by 2050 the world will require 840 million tons of wheat, excluding the demand for animal feed and considering the effects of climate change on wheat production. This means developing nations would need to increase their wheat output by 77% with development methods contributing over 80% of the supply (FAO, 2009).

The most significant cereal crop in Pakistan is wheat (Ali et al., 2019a). However, due to its continuous cereal cropping method and minimal or nonexistent application of organic matter, deficits in nitrogen and phosphorus severely restrict wheat productivity (Ali et al., 2019a). Apart from deflation of nutrients, this practice also leads to the development of a hard pan that might cause surface runoff and negatively impact on crop productivity (Yasnolo et al., 2018). Cereal mono-cropping, especially maize-wheat-maize, causes fast nutrient loss and erosion from crop harvest, therefore reducing soil fertility. In Pakistan, cropping techniques based on cereals are widely utilized because they provide food security, high productivity, and profitability. According to Laye et al. (2018), cereal crops are extremely demanding and need a large amount of nutrients to produce more products. In Pakistan, small-scale farmers typically work with substandard alkaline or saline soils, which leads to sterility and deficiencies in nitrates, phosphates, and other micronutrients. Frequently, ineffective solutions are implemented to address this issue (Burt et al., 2001). Legumes can help with this condition. Green manuring, including legumes in crop rotation, are thought to be the key ways to keep soil fertility and high crop yield (Meena et al., 2018; Yang et al., 2023).

However, Gogoi et al. (2018) have demonstrated a positive impact of legumes on the structure and function of the agroecosystem. Several studies have revealed improved crop quality and yield when planted legumes (Jalal et al., 2020). Legume farming guarantees the replenishment of nutrient-deficient soils and supplies animals and humans with necessary protein, mineral, and vitamin intake. Because of legumes fix nitrogen from the atmosphere, they may maintain the fertility of the soil. Although, it is necessary to step up efforts to use land wisely by applying fertilizers in a balanced manner with a focus on nitrogenous fertilizers. The bright use of nitrogen fertilizer increases crop yield and improves soil fertility. The addition of nitrogenous fertilizer raised the grain yield of maize from 43-68% and the biomass yield from 25-42% (Ogola et al., 2002). One of the most important variables limiting agricultural output and productivity is adequate nutrient management (Zhu et al., 2023, Ali et al., 2019b). Crop productivity has recently dropped as a result of decreasing soil fertility. Due to delays in the timely delivery of fertilizer producers are finding it difficult to maintain the soil's fertility. Confirming that a given soil has a tolerable supply of nutrients for optimal plant development is now the largest challenge, as soil types differ in their potential for production (Zhu et al., 2023).

Moreover, In Pakistan low soil fertility and increasing costs of artificial fertilizers are two of the main problems to a high grain yield. Reducing production costs, maintaining soil health and fertility, and raising crop productivity are all significant challenges facing agricultural scientists. Many solutions, including the use of organic materials (biochar), integrated nutrient management, and organic farming, are being explored globally to address these issues (Ali et al., 2011; Ullah et al., 2020). The addition of organic amendments is the simplest approach to boost soil productivity and stabilize crop yield, given the extremely low soil organic matter in degraded land (Amanullah et al., 2007; Ismail et al., 2011). However, the primary drawback of adding organic matter, particularly in moist tropical conditions, is its quick decomposition, which necessitates regular application during each planting season and is illogical given how difficult it is to get enough organic manure. Thus, refractory organic elements, such as "biochars," have been assessed by certain researchers for their potential to enhance soil qualities and carbon sequestration (Glaser et al., 2002; Liang et al., 2006; Ullah et al., 2021), and boost crop yields (Yamato et al., 2006; Chan et al., 2008). Through enhanced soil carbon (Lehmann et al., 2006), decreased greenhouse gas emissions, improved soil fertility, and greater agricultural production (Major et al., 2010), the effective use of biochar can help moderate climate change. Because of the high porosity of the biochar, the physical features of the soil, such as structure and water-holding capacity, are enhanced (Song et al., 2022; Ali et al., 2022; Karhu et al., 2011; Ullah et al., 2023; Vaccari et al., 2011), which lessens the drought stress on dry land that is increased by climate change. Biochar-amended soil improved crop nitrogen usage efficiency and decreased nitrogen demand, which may have a knock-on impact on lowering greenhouse gas emissions from the N fertilizer industry (Gaunt and Lehmann, 2008; Zheng et al., 2010).

The beneficial effect of biochar on crop yield and soil fertility has been reported by many scientists throughout the world (Ali et al., 2020a; Ali et al., 2020b; Ahmad et al., 2022, Ahmad et al., 2023) but yet need more study particularly in Pakistan. The main objectives of the current study are given (1) To evaluate the potential of biochar for soil management in cereal-cereal based cropping system with adjustment of legumes in the summer gap. (2) To determine the impact of biochar on yield and yield components and residual soil fertility. (3) To find out the beneficial effects of biochar as organic amendments in different cropping patterns would last longer compared to that of conventional organic manures such as farm yard manure or not.

2. Materials and methods

2.1 Experimental site

To study the residual impacts of biochar and legumes on wheat crop under different nitrogen rates, a field trial was conducted in the winter season of 2013-2014 at the Agronomy Research Farm, The University of Agriculture Peshawar. The experimental site is 340m above sea level. The soil type of the experimental site is considered as clay loam having a soil pH of 7.8, EC 1.2 and found to be deficient in Nitrogen (N), Phosphorous (P) and Potassium (K) contents i.e., N 16 mg kg^{-1}, P 8.0 mg kg^{-1} and K 50 mg kg^{-1}, respectively.

2.2 Experimental materials

The experiment was arranged in a

Table 1. Represent treatments of preceding legumes with and without biochar.

Codes	Treatments
T1	Mungbean (grain purpose) + 0 t ha^{-1}Biochar
T2	Mungbean (grain purpose) + 50 t ha^{-1}Biochar
T3	Cowpea (fodder purpose) + 0 t ha^{-1}
T4	Cowpea (fodder purpose) + 50 t ha^{-1}
T5	Sesbania (green manure) + 0 t ha^{-1} Biochar
T6	Sesbania (green manure) + 50 t ha^{-1} Biochar
T7	Fallow + 0 t ha^{-1} Biochar
T8	Fallow + 50 t ha^{-1} Biochar

Table 2. The treatments for the current wheat experiment were as follow along with the study of residual effects of the above mentioned legumes and biochar.

Wheat Experiment (Nitrogen Levels)	Treatment
N1	0 kg ha^{-1}
N2	60 kg ha^{-1}
N3	90 kg ha^{-1}
N4	120 kg ha^{-1}

Randomize Complete Block (RCB) design with four replications. The land was properly prepared by using a cultivator twice, followed by a rotavator for a smooth seedbed. The residual effect of summer legumes grown for grain, fodder and green manure purposes was studied on the subsequent wheat crop (Table 1). Mung-bean was used for grain purposes and cowpea was used for fodder purposes. Likewise, Sesbania were purely used for green manure purpose. A fallow treatment was included in the experiment as a control. Two levels of biochar (0 and 50-ton ha^{-1}) for legumes and four different N rates (0, 60, 90 and 120 kg ha^{-1}) were used for wheat crop (Table 2). N fertilizer was applied in two split doses i.e. half at sowing and half at booting. The subplot size for wheat was 5m by 4m.

Summer legumes, i.e. mung bean, cowpea and Sesbania with and without biochar, were sown in the first week of May following recommended agronomic practices. The biomass of Sesbania were incorporated into the field in the month of early July.

2.3 Data collection and measurements

Data on emergence m^{-2} was recorded by counting a total number of plants that emerged in one-meter row length at three randomly selected rows in each subplot. The data were converted to emergence m^{-2}. The plant height was measured as the distance from the base to the tip of the plant of five randomly selected plants in each sub-plot and was averaged. Grains from five randomly selected ears were obtained by hand threshing and were counted and converted into an average number of grains $year^{-1}$. Fifty grains were counted at random from the grain sample of each sub-plot of wheat and were weighed with an electronic balance and then converted into thousand grain weight. For recording grain yield data, three central three rows were harvested in each sub-plot with the help of a sickle. Samples were sun dried, threshed and grains were weighed with the help of an electronic balance and the data were converted into kg $ha^{-1.}$ Three central rows were harvested at maturity from each subplot, tied into bundles separately and were sun dried and weighed by spring balance for calculating biological yield. The data were converted into kg $ha^{-1.}$ Furthermore, harvest index was calculated and expressed in percentage for each plot using the following formula for each crop:

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biological yield}} \text{x}100$$

Wheat grain, straw and soil samples were analyzed for total N content. Wheat grain and straw samples were oven dried at 80 °C to a constant mass, weighed, then finely ground (< 0.1 mm) and analyzed for total N (Bremner and Mulvaney, 1982). The soil samples were air dried for one day, ground and then sieved (< 2 mm) and analyzed for total N following the Kjeldahl method of Bremner and Mulvaney (1982). Soil samples were collected at a depth of 0-15 cm from each sub plot.

2.4. Statistical analysis

The research data were statistically analyzed by using the statistical software Statistix version 8.1 and the hypothesis were tested via the statistical technique ANOVA for RCB design with split plot arrangement. The treatment means were compared and calculated at $P < 0.05$ level of probability by using the LSD test (Jan et al., 2009). Correlation analysis was done by using the R-studio Team (2020). RStudio: Integrated Development for R. RStudio, PBC, Boston, MA (URL; http://www.rstudio.com/.)

3. Results

3.1. Emergence m^{-2}

Analysis of the data indicated that emergence m^{-2} of maize were not significantly varied due to previously applied biochar, legumes or nitrogen applied to the current crop (Table 3). Though the effect of all treatments was found non-significant, higher emergence was recorded in plots previously treated with 50-ton ha^{-1} biochar as compared to no biochar treated plots. Similarly, more seedlings were counted in plots where sesbania was incorporated as green manuring, followed by ^{mung} bean, while lower emergence was recorded in plots previously sown with cowpea.

Table 3. Effects of biochar, nitrogen and legumes on wheat growth yield and yield components.

B rates	Legumes	N rates	Emergence m^{-2}	tiller m^{-2}	Spike m^{-2}	Grains $Spike^{-2}$	Thousand grain weight (g)	Grain yield (kg ha^{-2})
0	Cowpea	0	148	295	282	49	48.0	2210
0	Mungbean	0	141	357	344	50	47.0	2580
0	Sesbania	0	131	416	410	48	51.0	2508
0	Fallow	0	142	378	365	48	48.3	1892
50	Cowpea	0	126	373	360	48	50.3	2213
50	Mungbean	0	148	376	363	50	48.7	2432
50	Sesbania	0	121	360	355	51	46.7	2409
50	Fallow	0	123	364	351	50	48.7	2020
0	Cowpea	60	127	435	424	49	51.7	2810
0	Mungbean	60	130	446	435	47	52.0	3063
0	Sesbania	60	153	392	386	50	53.7	3000
0	Fallow	60	135	339	328	52	51.3	2494
50	Cowpea	60	139	395	384	52	52.7	2985
50	Mungbean	60	140	407	396	51	51.3	2971
50	Sesbania	60	154	439	428	52	50.0	2930
50	Fallow	60	140	392	381	53	49.3	2918
0	Cowpea	90	129	413	406	51	50.3	3481
0	Mungbean	90	143	422	415	51	51.3	3305
0	Sesbania	90	144	427	420	46	51.3	3142
0	Fallow	90	124	394	387	48	48.7	3293
50	Cowpea	90	111	443	432	59	54.0	4209
50	Mungbean	90	112	475	456	58	53.7	4225
50	Sesbania	90	119	459	452	61	54.3	3874
50	Fallow	90	122	459	452	53	49.0	3175
0	Cowpea	120	120	415	408	58	49.3	3846
0	Mungbean	120	123	393	386	57	49.0	3660
0	Sesbania	120	134	393	357	55	47.0	3298
0	Fallow	120	142	360	353	56	49.7	3979
50	Cowpea	120	157	417	407	56	50.0	4151
50	Mungbean	120	156	444	434	53	52.0	4052
50	Sesbania	120	157	458	455	49	51.7	4037
50	Fallow	120	154	406	399	47	51.7	3865
Source of variation			Emergence	Tiller	Spikes	Grains	TGW	Grain yield
Biochar (B)			ns	*	*	*	*	*
Legumes (L)			ns	ns	ns	ns	ns	ns
Nitrogen (N)			ns	ns	ns	ns	ns	*
B×L			ns	ns	ns	ns	ns	ns
B×N			ns	ns	ns	*	*	ns
L×N			ns	ns	ns	*	ns	*
B×L×N			ns	**	ns	ns	ns	*

Note: Values followed by the same letters, within column, are not significantly different at $P \leq 0.05$. SOV- source of variation, ** indicate the significant difference $P \leq 0.01$ and * indicate $P = 0.01 - 0.05$. ns-non-significant.

3.2 Yield and yield components

The application of biochar significantly affected tillers m^{-2}, spikes m^{-2}, grains $spike^{-1}$, thousand grain weight (g), and yield (kg ha^{-1}). However, the impact of legumes, nitrogen (N), and the interaction between biochar and legumes (B×L) was not significant, except for grain yield. Furthermore, B×N considerably affected grains $spike^{-1}$ and thousand grain weight (g), while B × L× N significantly influenced tillers m^{-2} and grain yield (Table 3). Plots treated with 90 kg ha^{-1} and 120 kg N ha^{-1} exhibited higher tillers m^{-2}, while control plots with N application had lower tillers m^{-2}. Biochar at 50-ton ha^{-1} increased tillers m^{-2} compared to non-biochar plots. The effect of legumes was not significant, but sesbania incorporation led to higher tillers m^{-2}, while cowpea resulted in lower tillers m^{-2}. Data on spike m^{-2} showed that biochar-treated plots had higher spike m^{-2} than non-biochar plots. Spike m^{-2} increased with N application up to 90 kg ha^{-1}, and plots with 90 kg N ha^{-1} had similar spike m^{-2} to 120 kg N ha^{-1}. Sesbania incorporation, similar to mung bean, resulted in more spikes. Fallow plots had a lower number of spike m^{-2}.

Biochar (50-ton ha^{-1}) application resulted in a higher number of grains $spike^{-1}$ compared to plots without biochar. Similarly, a higher number of grains $spike^{-1}$ was observed with 120 kg N ha^{-1}, which was statistically similar to N application at 90 kg ha^{-1}. Control plots (0 kg N ha^{-1}) exhibited lower grains per spike. In terms of thousand grain weight, plots with previous biochar application at 50-ton ha^{-1} recorded higher weights, while no biochar plots had lighter grains （Table 3). Nitrogen application at 90 kg ha^{-1} produced heavier grains, similar to 60 kg ha^{-1}, followed by 120 kg ha^{-1}. Control plots had lower thousand grain weights. Plots treated previously with 50-ton ha^{-1} biochar yielded higher wheat grain compared to no biochar plots (Table 3). Additionally, 90 kg N ha^{-1} resulted in a greater grain yield, statistically similar to the yield obtained with 120 kg N ha^{-1}) （Table 3). Grain yield was lower in control plots. Regarding legumes, including (cowpea, sesbania, and mung bean) produced higher grain yields compared to fallow plots.

The plots treated with 50-ton ha^{-1} biochar outperformed those without biochar, displaying a higher biological yield. A consistent linear increase in biological yield was observed with rising nitrogen levels. Specifically, plots treated with 120 kg ha^{-1} N showed the highest biological yield, followed closely by those with 90 kg N ha^{-1}. Contrastingly, control plots exhibited a lower biological yield (Figure 1). Although the impact of legumes was statistically non-significant, plots previously sown with legumes exhibited a notably higher harvest index compared to fallow plots. Moreover, a significant difference emerged with N applications: a superior harvest index resulted from the application of 120 kg ha^{-1} N, while a slightly lower harvest index was observed with 90 kg ha^{-1} N. Control plots, as demonstrated the lowest harvest index (Figure 1).

3.3 N contents in soil, grain and straw of different legumes

Application of biochar at a rate of 50 tons ha^{-1} led to a higher grain N content (2.25%) compared to plots without biochar amendment (2.05%) (Table 4).

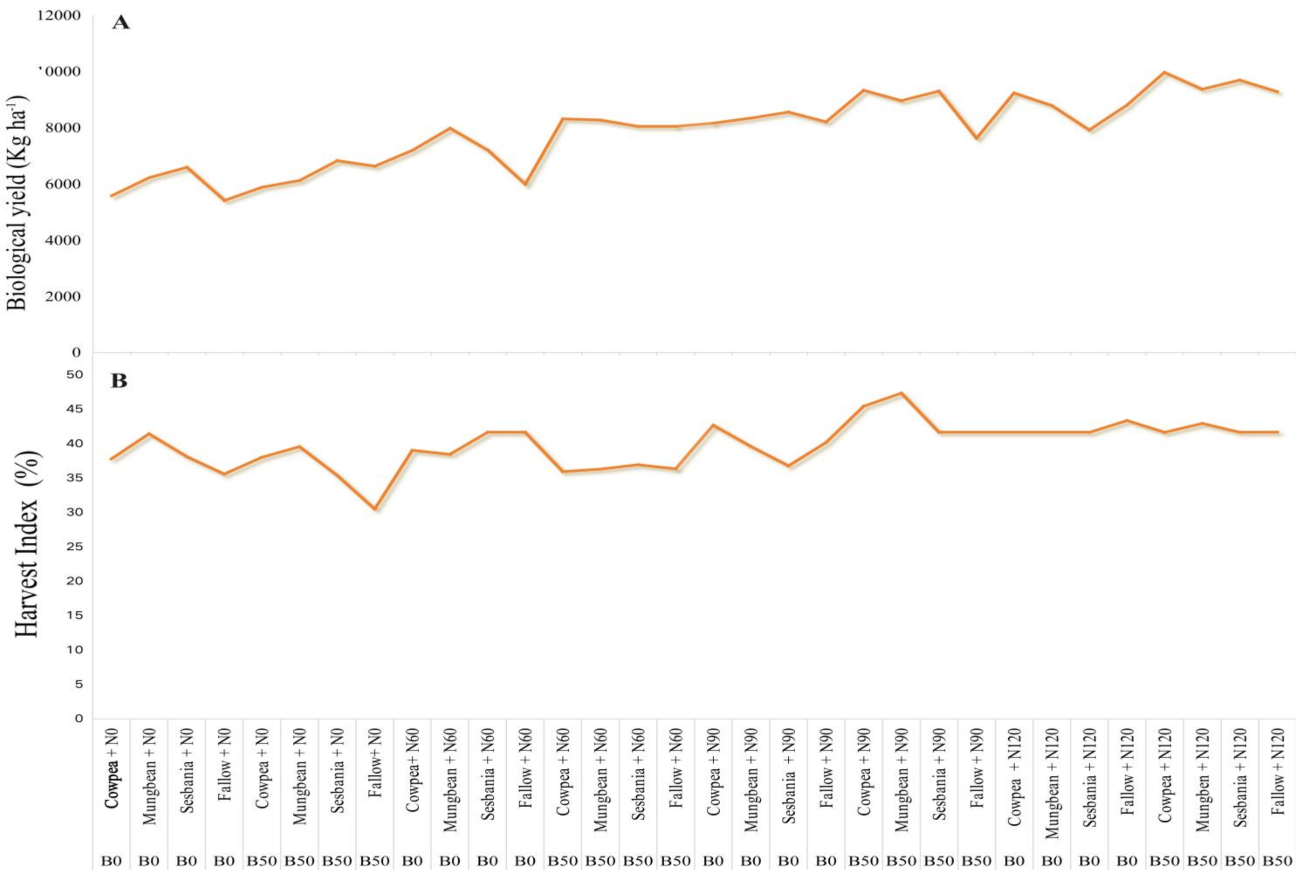

Figure 1. Impact of various biochar and nitrogen levels on biological yield and harvest index of different legumes. Note: B0 and B50 indicated biochar 0 and 50 tin ha^{-1}, while N0, N60 and N120 indicate nitrogen rates of 0, 60 and 120 kg ha^{-1}

The grain N content exhibited a linear increase with the N application rate, reaching its peak (2.23%) in grains collected from plots treated with 120 kg ha^{-1} N, followed closely by 90 kg N ha^{-1} (2.14%). Control plots exhibited a lower grain N content (1.97%). Incorporating sesbania resulted in a higher grain N content (2.19%), comparable to cowpea and mung bean sown plots, while fallow plots showed a lower grain N content (1.75%) (Table 4).

For straw N content, plots previously sown with mung bean displayed a higher value (0.47%), equivalent to sesbania incorporated plots. Fallow plots exhibited a lower wheat straw N content (0.37%). Additionally, N application at a rate of 120 kg ha^{-1} resulted in higher straw N content (0.47%), followed by 60 kg ha^{-1} N (0.43%), whereas control plots displayed a lower wheat straw N content (0.42%). In terms of soil N content, plots treated with 50 tons ha-1 biochar exhibited higher levels (0.07%) compared to plots without biochar (0.06%).

Furthermore, N application at a rate of 120 kg ha^{-1} resulted in elevated soil N content

Table 4. Nitrogen contents in grain, straw and soil after biochar and N application of different legumes.

Biochar rates (ton ha^{-1})	Legumes	N rates (kg ha^{-1}	Grain N content (%)	Straw N content (%)	Soil N content (%)
0	Cowpea	0	1.88	0.4	0.05
0	Mungbean	0	1.85	0.39	0.05
0	Sesbania	0	1.93	0.41	0.05
0	Fallow	0	1.79	0.38	0.04
50	Cowpea	0	1.94	0.41	0.06
50	Mungbean	0	2.17	0.46	0.06
50	Sesbania	0	2.38	0.51	0.06
50	Fallow	0	1.82	0.39	0.05
0	Cowpea	60	2.44	0.52	0.07
0	Mungbean	60	2.2	0.47	0.07
0	Sesbania	60	2.43	0.52	0.06
0	Fallow	60	1.79	0.38	0.04
50	Cowpea	60	2.58	0.55	0.06
50	Mungbean	60	1.81	0.39	0.06
50	Sesbania	60	1.85	0.39	0.06
50	Fallow	60	1.93	0.41	0.06
0	Cowpea	90	1.85	0.39	0.06
0	Mungbean	90	1.94	0.41	0.06
0	Sesbania	90	2.17	0.46	0.07
0	Fallow	90	1.78	0.38	0.04
50	Cowpea	90	2.27	0.48	0.08
50	Mungbean	90	2.44	0.52	0.08
50	Sesbania	90	2.2	0.47	0.07
50	Fallow	90	1.38	0.29	0.05
0	Cowpea	120	2.4	0.51	0.08
0	Mungbean	120	2.58	0.55	0.09
0	Sesbania	120	2.27	0.48	0.08
0	Fallow	120	1.84	0.39	0.04
50	Cowpea	120	2.2	0.47	0.07
50	Mungbean	120	2.43	0.52	0.08
50	Sesbania	120	2.4	0.51	0.08
50	Fallow	120	1.69	0.36	0.06
Source of variation			Grain N	Straw N	Soil N
Biochar (B)			*	ns	*
Legumes (L)			ns	ns	ns
Nitrogen (N)			ns	ns	ns
B×L			ns	ns	*
B×N			*	ns	*
L×N			*	*	*
B×L×N			*	*	*

Note: N-nitrogen, Values followed by the same letters, within column, are not significantly different at $P \leq 0.05$. SOV- source of variation, ** indicate the significant difference $P \leq 0.01$ and * indicate $P = 0.01 - 0.05$. ns-non-significant.

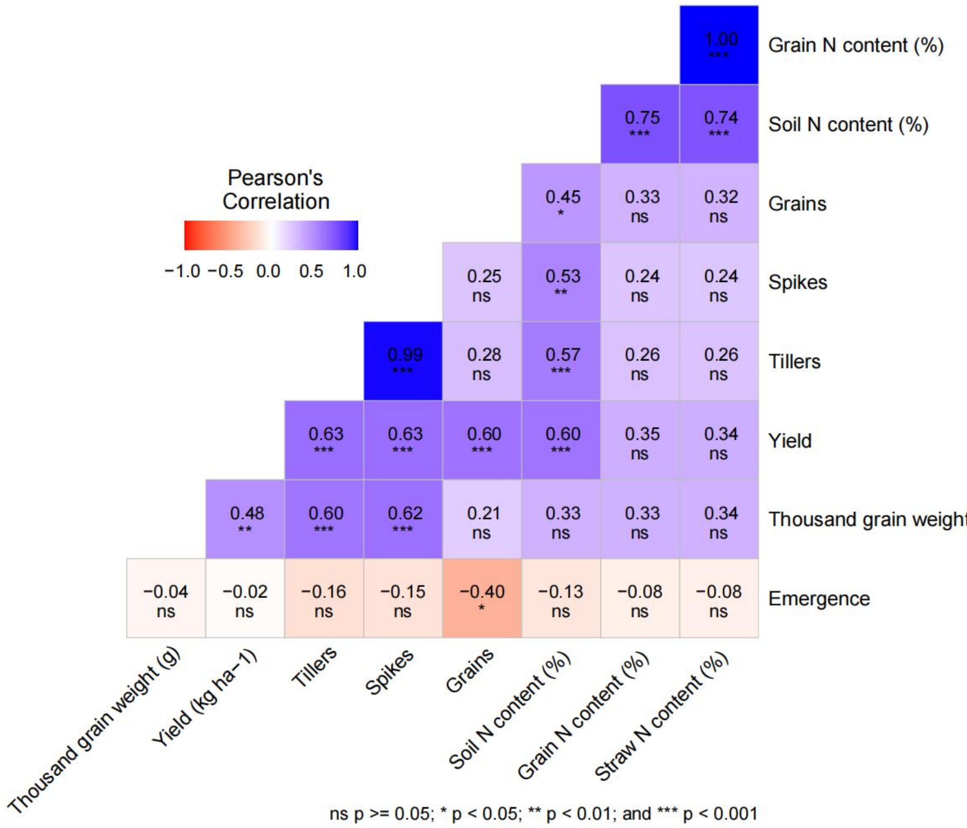

Figure 2. Correlation analysis among all traits across the biochar and N treatments.

(0.07%), followed by 90 kg N ha^{-1} (0.06%), while control plots displayed lower soil N content.

3.4 Relationship of growth, N contents and grain yield

The correlation analysis was performed by using R Studio, utilizing the "metan" package (Figure 2). The findings revealed significant correlations between straw nitrogen (N) content (R=0.74) and grain N content (R=0.75) with soil N content, as illustrated in Figure 2. Moreover, the grain yield of wheat exhibited noteworthy correlations with various factors: tillers (R=0.63), grains (R=0.60), soil N content (R=0.60), grain N content (R=0.35), and straw N content (R=0.34). These results emphasize the intricate interplay between soil and plant components, shedding light on key relationships that influence wheat productivity.

4. Discussion

The terminal objective of various organic and inorganic amendments is to improve crop yield due to different processes and biochemical changes in the soil as well as due to various anthropogenic activities. Crop yield is the ultimate task of various nutrient management practices aiming to increase income. Various yield components and growth parameters (grains spike^{-1}, 1000 grains weight, grain yield and total biomass) of wheat significantly enhanced with the use of biochar, mineral nitrogen and previously sown legume as compared to no biochar, control and fallow, respectively. Mineral N application resulted in 51%, 65%, 12%, 12%, 12%, 12% and 12% in tiller m^{-2}, spikes m^{-2}, grains $spike^{-1}$, thousand grain weight, grain yield, biological yield and grain and stover N contents respectively.

However, nitrogen application significantly enhanced tillers m^{-2} as compared to control. The minimum tillers in control plots probably may be due to the exhaustive effect of wheat in terms of nutrient absorption that led to nutrient deficiency and poor crop performance (Salim et al., 2020). The fact that tillers m^{-2} of wheat varied significantly with the application rate of nitrogen strongly underscores the necessity of an accurate N application rate to match nutrient supply to crop demand. Nitrogen application resulted in 27% increase, while previously applied biochar caused a 30 % increase in wheat spikes m^{-2} over control. Wheat spikes m^{-2} positively responded to the N sources, either organic or inorganic, which might be the reason that biochar has a carry-over effect. The lower number of spikes m^{-2} due to lower N level was may be due to the lower availability of nitrogen during plant growth (Ciampitti et al., 2012). Rehman et al. (2008) also reported that a combination of NPK and FYM gave a higher number of spikes m^{-2}. Biochar ensures greater nutrient retention and water holding capacity of the soil (Lehman et al., 2003) might have produced more tiller and spike m^{-2} in biochar treated plots over control. Higher tiller and spike m^{-2} were counted in plots sown after legume crops (i.e., Cowpea, sesbania and mungbean).

Moreover, Nitrogen application significantly improved number of grains $spike^{-1}$ of wheat over control and this increase could be accredited to higher levels of available N for plant uptake (Ullah et al., 2013). Our results are confirmed by the findings of Costa et al. (2002) who stated an increase in spike length and diameter via the addition of N up to an optimum level and higher level did not increase in both of the parameters considerably. Biochar application convincingly improved the number of grains $spike^{-1}$ as compared to the control. This increase in grains $spike^{-1}$ may be attributed to the slow release of N from biochar in these plots. Our results are similar to those reported earlier by Lehmann et al. (2003). This increase could be accredited to the positive effect of biochar on soil organic matter nutrient holding capacity as well as available N during the growth period and the improvement in moisture content of the soil (Brar et al., 2001). Thus, biochar amended plots had more grains $spike^{-1}$ as compared to control plots. Likewise, other yield components of thousands of grain weight of wheat were synergistically improved by nitrogen application rate. The increase in thousand grain weight has been attributed to the increased application rate of nitrogen fertilizer (Ullah et al., 2013). Similar results were reported by Makowska et al. (2008), who found an increase in thousand grain weight of wheat by increasing the level of nitrogen. Significantly the greater 1000-grain weight of wheat in biochar amended plots over control might be due to higher uptake of P because of its involvement in grain development as biochar application improved soil P content in the experimental fields.

Further, the Biological yield of wheat increased in N applied plots over control. It could be attributed to higher plant height in N treated plots and positive impact of N on vegetative growth. More leaves $plant^{-1}$ and leaf area could be noted in nitrogen fertilized plots (Shafi et al., 2012) which ultimately improved biological yield of wheat in fertilized plots. These findings are in full agreement with that of Muhammad and Hassan (2011) who reported that the increase in leaf to stem ratio with nitrogen application is probably due to the increase in number of leaves and leaf area under nitrogen treatments, producing more and heavy leaves in result biological yield is increased.

Additionally, Biochar application increased grain yield of wheat as compared to control. This increase in biochar amended plots could be attributed to nutritional value of biochar. Biochar increase crop productivity by applying nutrient directly to the crop or by improving soil fertility and productivity and enhance fertilizer use efficiency especially nitrogenous fertilizer by reducing leaching of N (Ullah et al., 2021). Other reasons for the increase in grain yield due to biochar application could be its ability to enhance organic matter mineralization (Wardle et al.,1998) and improved crop yield and growth (Chan et al., 2007). Technically, biochar acts as a buffer and contains some essential plant nutrients which influentially increase crop yield. Therefore, grain yield was considerably enhanced with higher rates of biochar. Being a comprehensive and multifunctional entity, biochar increases soil fertility, organic matter, porosity, and improves nutrients availability and nutrients use efficiency in crops. Uzoma et al. (2011) achieved similar results and also stated that biochar incorporation in soil at the rate of 30 and 20-ton ha^{-1} would significantly increase maize grain yields by 150% and 98% as compared with the control, respectively. Moreover, the increase in soil organic matter content improved the physical properties of the soil and would have caused increased root development that acted positively in more uptakes of water and nutrients and caused increase in wheat grain yield (Khan et al., 2008; Ali et al., 2012).

Combined application of organic and inorganic fertilizers affirmatively affects wheat grain yield owing to incorporation of sesbania which improves soil physical properties. Use of mineral fertilizers increases mineralization and makes the soil more productive (Ali et al., 2011). These results are in line with Negassa et al. (2001) who found that maize yield was 35% increased by integrated N management. The significant correlations between soil and plant variables was noticed in the study. Notably, the strong correlations of straw nitrogen (N) content (R=0.74) and grain N content (R=0.75) with soil N content highlight the intricate interplay within the soil-plant system. Additionally, the noteworthy associations observed between grain yield of wheat and key factors such as tillers (R=0.63), grains (R=0.60), and soil N content (R=0.60) further elucidate the complex dynamics influencing wheat productivity. These findings contribute valuable insights to our understanding of the nuanced connections shaping agricultural outcomes.

5. Conclusion

Our results concluded that previously incorporated biochar at the rate of 50-ton ha^{-1} improved yield and yield components of wheat and enhanced nitrogen (N) content of soil. In addition, previously sown legumes i.e., mungbean, cowpea and Sesbania for grain, fodder and green manuring purposes, respectively had positive effects on wheat yield and yield components and soil N status. Higher grain yield of wheat was recorded with 120 kg N ha^{-1} but it was at par with 90 kg N ha^{-1} when sown after legumes. Therefore, it is recommended that 50 t B ha^{-1} is suitable for soil health and sowing of legumes like cowpea, mungbean and Sesbania in summer gap are recommended for getting fodder, grain or biomass for green manure, respectively. Furthermore, nitrogen level of 90 kg ha^{-1} instead of 120 kg ha^{-1} is recommended for having higher grain yield of wheat if sown after legumes.

Green manuring at post flowering stage resulted in the lowest AE (6.6 kg kg^{-1}). Among N levels, the N application at the rates of 70 and 100 kg ha^{-1} had higher and statistically similar AE (11.8 and 10.3 kg kg^{-1}, respectively) as compared to 130 kg N ha^{-1} (9.1 kg kg^{-1}).

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